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Exploring Frameworks for

TropicalForest Conservation

Integrating Natural and Cultural Diversity for Sustainability, a Global Perspective

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Tropical Forest Conservation

Integrating Natural and Cultural Diversity for Sustainability. A Global Perspective

Published in 2018 by the UNESCO Office in Mexico, Presidente Masaryk 526, Polanco, 11560, Mexico City, Mexico, in collaboration with the Ecology Institute, Camino Antiguo a Coatepec, El Haya, 91070 Xalapa Enríquez, Veracruz.

ISBN: 978-607-7579-79-3

Original idea, concept, coordination and supervision of the editing and publication: The UNESCO Office in Mexico.

Conception, Edition and General Coordination of the project:
Nuria Sanz, Head and Representative, UNESCO Office in Mexico

Editorial work:
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Graphic and cover design:
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The UNESCO Office in Mexico would like to thank to Professor Robin Dennell,
member of the Scientific Committee of the World Heritage Thematic Programme HEADS.

Printed in Mexico.

Editor
Nuria Sanz

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Abstract

The island of New Guinea contains some of the most extensive tracts of tropical rainforest in the world. Like Amazonia, the Congo Basin and Borneo, the tropical rainforests on New Guinea are today being heavily disturbed, degraded and destroyed by a combination of competing land uses, primarily subsistence and commercial agriculture, oil palm arboriculture and logging (Mack, 2014; Bryan, 2015; also see Tollefson, 2008; Ghazoul and Sheil, 2010). Yet, present-day human impacts on tropical rainforests need to be evaluated against long-term temporal trajectories during which people have acculturated, and effectively domesticated, these forest landscapes.

Long-Term Records of Human Adaptation and Tropical Rainforest Conservation in Papua New Guinea: Translating the Past into the Present

The tropical rainforests of New Guinea are not 'virgin' or 'pristine' (Willis et al., 2004), rather they are cultural landscapes that bear the imprint of human activities for tens of millennia (Balée, 1989; Yen, 1989; Terrell et al., 2003; Barker et al., 2008). As soon as people entered tropical rainforests they began to change, as well as adapt to, them. The degree, timing and extent of these changes are highly variable for locations and valleys on the island of New Guinea. Any attempt to manage tropical rainforests into the future needs to take into account how they were created in the past, as well as the changing needs of the people who inhabit them today and their ways of life.

Here long-term changes to the tropical rainforests of New Guinea are inferred from archaeological and palaeoecological records that document human activities since colonisation in the Pleistocene, as well as the development of more intensive arboriculture and the emergence of agriculture during the Holocene (last c. 11,600 years). The focus here is upon the highlands (namely, land above 1200 m altitude) of Papua New Guinea because archaeological and palaeoecological records are far more comprehensive than for lowlands. These long-term records, which vary greatly in terms of geographical and temporal coverage, form the fluctuating backdrop, or baseline, against which modern human impacts on tropical rainforests can be assessed and future conservation strategies developed.

From Sunda to Sahul

Although archaeological evidence is sparse, several models have been proposed to account for the ways modern humans spread across Southeast Asia, effectively the biogeographical region known as Sunda. Irrespective of whether people spread along coasts and estuaries (Bulbeck, 2007), through rainforest (Barker, 2014) or followed savanna corridors (Bird et al., 2005), they certainly became adapted to tropical rainforest environments. The multi-disciplinary evidence from Niah Cave on Borneo (Barker, 2014) clearly demonstrates that people had the technological know-how to inhabit the tropical rainforests of Island Southeast Asia from 50,000–40,000 years ago, including toxic food processing (Barton and Paz, 2007) and specialised hunting tools (Barton et al., 2009).

Modern humans colonised New Guinea, including coastal and highland regions, by at least 45,000 cal BP (Groube et al., 1986; Summerhayes et al., 2010). New Guinea and Australia formed one contiguous landmass from that time until post-glacial sea level rise created the Torres Strait around 8000 years ago. Hunting-gathering-fishing populations, or foragers, inhabited a diverse range of environments on this continent through the adaptation of a relatively generic technological suite, common practices, and shared orientations (see Denham et al., 2009). This adaptive flexibility enabled people to inhabit semi-arid, temperate, savannah and tropical rainforest environments across Sahul soon after colonisation, as they had done on Sunda. Here the focus is upon the rainforests of tropical Papua New Guinea.

Prior to the arrival of people, New Guinea would have been carpeted in forests, including highly diverse lowland and montane rainforest, as well as upper montane, beech (*Nothofagus*)-dominated forest (Powell, 1976; Gressitt, 1982; Hope and Golson, 1995); higher altitudes comprised alpine grassland and glaciers (van Royen, 1980). In order to understand the long-term dynamics of human-rainforest interaction, though, the focus is on the highlands (land above 1200 m altitude) because this region has more comprehensive archaeological and palaeocological records. People undoubtedly inhabited the lowlands from initial colonisation yet there is little long-term information - especially away from the coast, former Sepik-Ramu inland sea and major rivers - for the Pleistocene or most of the Holocene that sheds light on how people adapted to the interior rainforests in the lowlands (Fairbairn, 2005). Potential exceptions include the largely unpublished site of Seraba in the Lower Sepik (Gorecki, 1993; Yen, 1990) and Dongan Midden in the Lower Ramu (Swadling et al., 1989; Fairbairn and Swadling, 2005) that show arboreal plant exploitation from the Late Pleistocene and mid-Holocene, respectively.

Before embarking on a consideration of how palaeoecological and archaeological data can be used to provide long-term baselines, it is first necessary to address several common misconceptions regarding human-rainforest interaction. Only then can the primary lines of evidence – palaeoecological and archaeological – be reviewed, with an emphasis on the highlands region. The last section considers the ways in which these long-term records of human adaptation, interaction or impact can be used to inform tropical rainforest conservation in the present.

Common Misconceptions

In terms of human occupation of tropical rainforests, Barton et al. (2012, p. 2) observed the following:

> Despite the uniqueness of each cultural engagement, several commonalities can be elicited that enabled hunter-foragers to permanently inhabit rainforest landscapes in different parts of the world. These commonalities reflect a shared orientation of modern humans to their world, even though this orientation was differentially expressed in specific historical and geographic settings. Commonalities include: disturbance of the forest environment, primarily through burning, as well as localised modification of species composition of rainforest; exploitation of fauna through gathering, hunting and scavenging; a focus upon [oil,] protein and starch rich plants, primarily trees [as well as palms and pandans] and tuberous plants; and mobility.

Modern humans have been able to adapt to, and live in almost every type of environment, from deserts to ice caps. Yet, there is an impression that people did not inhabit tropical rainforests on a permanent basis prior to agriculture without altering them to any large extent, or without access to coastal, lacustrine or riverine resources. This 'green desert' hypothesis persists (Bailey et al., 1989; Bailey and Headland, 1991), yet lacks conceptual and evidential foundation (Denham, 2016a).

On a conceptual level, a scenario that asserts people could not have lived in rainforests unless they significantly modified their environment is nonsensical, fallacious and un-worldly. Wherever people have gone, they deliberately or inadvertently transformed their environment. People have altered species compositions by fishing, hunting and collecting. People disturbed rainforests through burning, ring-barking and pollarding, which cumulatively contributed to changes in biodiversity, such as the modification of species compositions, distributions and densities. For instance, people created niches in the rainforest for food procurement and to intensify the density of favoured resources in the landscape, whether of useful plants or to aid hunting. People have redistributed species around the landscape, often inadvertently through food discard and rubbish heaps, as well as through the creation of favourable ecological niches around settlements and the deliberate translocation of plants and animals.

Palaeoecological records for New Guinea indicate that people have disturbed some montane and lowland tropical rainforests since the Pleistocene (Haberle 1994, 2007), and most likely following initial colonisation. Although the stone tool kit of early colonisers, including the waisted blade, was not suitable for cutting trees down, it enabled people to kill trees by ring-barking, to clear and smash undergrowth, and prevent regrowth (Groube 1989). Together with fire, this tool kit was sufficient for people to transform their rainforest environment. The advent of fully-ground adzes during the mid-Holocene would have enhanced the ability of people to clear-fell forest (Christensen, 1975), and the cumulative degradation and clearance of some montane valleys can be traced to this time (Hope and Haberle, 2005; Haberle et al., 2012).

Certainly, large-scale transformations to tropical rainforests in the interior of New Guinea, including for agriculture, had occurred before the advent of metal tools within the last few hundred years (contra Denevan, 2001). Although some metal axe-heads and knife blades were traded into the interior of New Guinea ahead of direct contact (Hughes, 1977), these items only became commonly available after direct contact with colonial administrators, gold prospectors and missionaries from the early 1930s onwards (Connolly and Anderson, 1987). By that time, the floors of several inter-montane valleys had been denuded of rainforest for millennia.

Having recognised that people have transformed rainforests for as long as they have lived in them, it is a matter of some debate whether tropical rainforests are abundant in 'ready-at-hand', edible resources. People have learned to live in rainforests – a 'landscape learning' process that extends over tens of millennia and predates the colonisation of Sahul. Part of this process has been learning to see food availability. Whereas a stranger might initially be drawn to edible fruits, nuts and tubers – and much archaeological literature focuses on these plant groups – such myopia misses a whole range of other edible plants in rainforest environments, including: palms, ferns and grasses rich in sago, or edible pith; grasses that yield sugar-rich juices or are cooked as vegetables; the various ferns and leaves that can be eaten cooked as green vegetables or eaten raw as salad; and, the numerous flowers, inflorescences and seeds (Powell, 1982; Schmid, 1991).

Broad-spectrum plant exploitation practices provided the range of nutrients to sustain human diets in the New Guinea rainforest; for example, Golson (1991, p. 87) has characterised resource availability in the lower montane rainforests:

> [T]he mixed oak forest is a favourable environment for plant-food procurement. Besides *Castanopsis* itself, which produces prolific quantities of small nuts, Bulmer and Bulmer (1964, p. 69) list a number of other trees with edible nuts and seeds, including *Elaeocarpus*, *Sloanea*, *Finschia*, *Sterculia* and especially *Pandanus* …; vines with edible fruits; many trees, shrubs and ferns with edible foliage; many kinds of edible fungi; and wild edible yam-like tubers, apparently of the genus *Dioscorea*. Of this corpus of edible plants only *Pandanus* is at home in the beech [*Nothofagus*-dominated] forest … (Golson 1991, p. 87).

Much literature on plant exploitation in the past has focused on carbohydrate-rich plant exploitation (e.g., Denham and Barton, 2006), often to the detriment of protein and oil-rich plants (Bourke, in press). Starch, protein and oil-rich plants tend to be more visible in the archaeological record, either through macrobotanical remains of nut shells, fruit stones and the occasional charred tuber, or through microfossil analysis of preserved phytoliths and starch grains. Although these food groups are fundamental to human diet, a carbohydrate fixation has emerged in some archaeological literature that fails to adequately encompass broad-spectrum plant exploitation. People in the past exploited a much larger range of plants than most present-day horticulturalists. Most contemporary agricultural societies have a relatively narrow diet breadth, especially in terms of staples and vegetables, and are not good analogues to understand plant exploitation in the distant past.

The stranger to the rainforest might at first be drawn to familiar types of faunal resources that are fished or hunted, such as birds, fish, lizards, mammals, shellfish and snakes – upon which much zooarchaeological literature has focussed (Sutton et al., 2009). In doing so, they miss the high percentages of fats and protein derived from the collection of small to very small faunal resources, including frogs, grubs, honey, insects, reptile eggs, spiders and so on. Before the introduction of domesticated chickens (*Gallus gallus*), dogs (*Canis familiaris*) and pigs (*Sus scrofa*) in the last few thousand years, rainforest inhabitants of the highlands and fringe highlands were reliant on the regular, small-scale collection of micro and meso-faunal resources, periodic hunting and occasional fishing.

New possibilities for understanding how people adapted to tropical rainforests in the past emerge once we move beyond several common misconceptions, namely, that rainforests were green deserts, people needed metal tools to clear tropical rainforests, and people focussed on carbohydrate rich plants. The rainforests of New Guinea are a cultural landscape; they bear the imprint of a human presence that has lasted tens of millennia. Broad-spectrum practices enabled people to live perma-

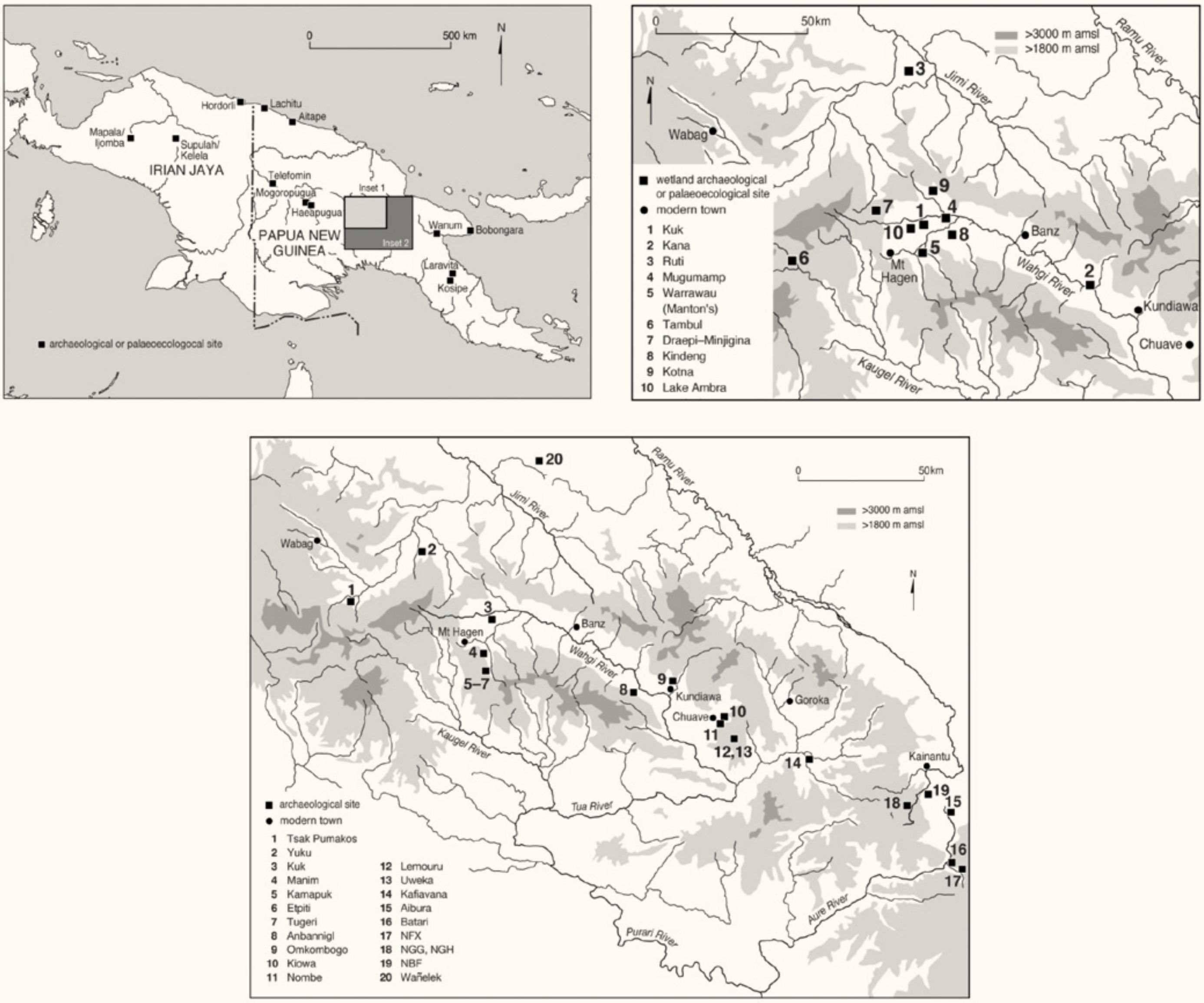

Figure 1. Map of New Guinea showing the location of archaeological and palaeoecological sites mentioned in the text (upper left) with insets depicting wetland (upper right) and occupation (lower right) sites in the highlands.

nently within the tropical rainforests of the highlands, even though population densities were probably low and mobility high.

Lines of Evidence 1. Palaeoecology

Palaeoecology, largely palynology (pollen, microcharcoal and phytoliths), provides a relatively comprehensive record of environmental change from the late Pleistocene to present for New Guinea (Haberle 1994, 2007; Hope and Haberle, 2005). This work has enabled the reconstruction of changes in vegetation communities at different altitudes and ecological zones through time (Figures 1 and 2; Hope, 1996, 2009; Hope and Hope, 1976). Initial studies

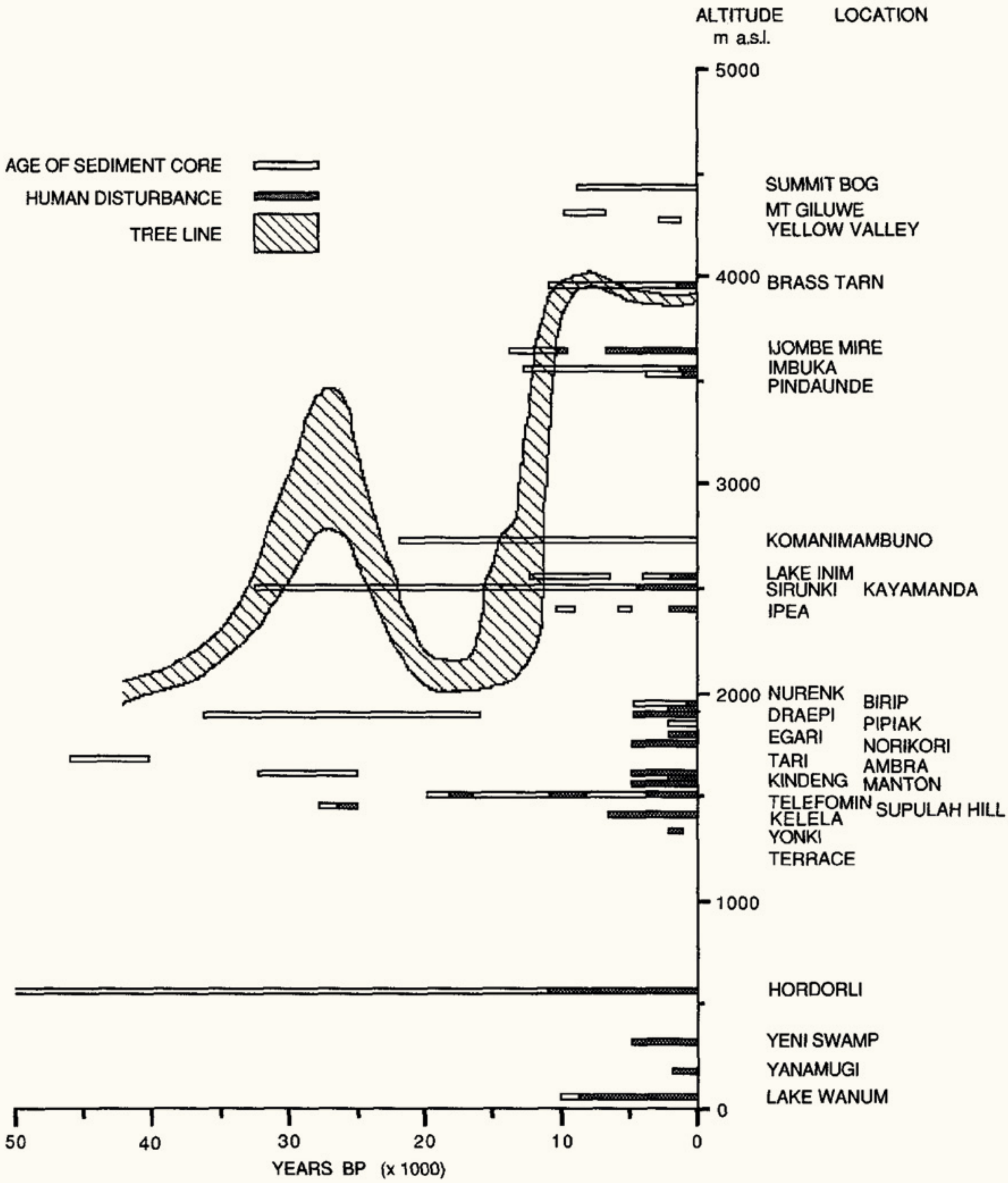

Figure 2. Diagram showing the extent of forests reconstructed from pollen records from different altitudes across the island of New Guinea (Haberle 1994: Fig. 8.2). Note the changing tree line in response to glacial cyclicity, as well as inferred periods of human disturbance that become more prevalent throughout the Holocene.

focussed on climatic causes of environmental change (e.g., Flenley, 1967; Hope, 1976), whereas more recent studies explicitly sought to differentiate anthropogenic and climatological influences on palaeoecology (e.g., Haberle, 1994, 2007; Walker and Hope, 1982; Haberle et al., 2012). The interpretation of pollen and related charcoal particle frequencies not only requires differentiation of local and regional signals, it also requires consideration of on-site changes in local hydrology and geomorphology.

Climatic Fluctuations

In Highland New Guinea, climatic amelioration after the last glacial maximum (LGM) commenced at c. 14,000 cal BP with the rapid amelioration of climates from 12,000 cal BP and stabilisation by approximately 9000 cal BP (Brookfield, 1989; Haberle, 1998). Climatic variability can be traced in New Guinea from glacial retreats and readvances, such as those on Mount Jaya (Hope and Peterson, 1975), and fluctuations in tree line (Hope and Hope, 1976; Walker and Hope, 1982). This regional chronology mirrors global climate change reconstructed from ice volume calculations (Martinson et al., 1987) and sea level curves (Lambeck and Chappell, 2001).

The traditional interpretation of climatic oscillations since the LGM consists of general trends with millennial and centennial-scale fluctuations, such as Heinrich and Bond events, including the Younger Dryas, the 8.2k event, the 4.2k event and the 'Little Ice Age' (e.g., Lamb, 1977; Grove, 1988; Bond et al., 1992). New research is suggesting that millennial and decadal climatic variations of greater magnitude and frequency than previously appreciated existed in the Terminal Pleistocene. However, the imprint of millennial climatic fluctuations, such as the Younger Dryas colder episode at 12,900–11,500 cal BP, are less clear for the southern hemisphere, especially away from the Atlantic Ocean (e.g., Chappell, 2001). On New Guinea, such events would differentially affect climates at different altitudes with corresponding changes in tree line and the availability of faunal and floral resources.

Although of Pleistocene antiquity, El Niño Southern Oscillation (ENSO) events intensified in the mid Holocene and, even though individually of short duration, would have impacted vegetation and human practices over the long-term (Tudhope et al., 2001). Problems in attempting to correlate the initiation of ENSO events and human adaptations to these events stem from seeking to reconcile high precision, annular-scale records of ENSO derived from ice cores, coral and other proxies with low precision archaeological records from the highlands.

Climatic fluctuations have two major implications for understanding past human occupation of tropical rainforests in New Guinea. First, variations in climate, particularly if they lead to severe frosts (Waddell, 1973) and droughts (Allen, 2000) affect resource availability. If these events are of frequent periodicity, then people may have adapted strategies to reduce impacts and to maintain their subsistence base. Second, variations in climate will affect the degree to which human practices impact the landscape. An apparent increase in the degree of disturbance, potentially measured in pollen diagrams from the frequencies of charcoal particles and disturbance taxa pollen, may not represent an intensification or involution of practices; it may solely represent the increased susceptibility of the landscape to continuing practices.

Anthropogenic Disturbance

Diagnostics for anthropogenic burning for New Guinea include: "The signature of a human induced fire regime appears to be one of frequent firing over an extended period of time associated with disturbance elements and reduced forest cover in the pollen record" (Haberle 1993, p. 117; also see Haberle et al., 2012). Additionally for grassland communities, the "carbonised particle curve corresponds with the grass [pollen frequency] curve" (Haberle 1994, p. 191). The major problem in the interpretation of charred particle records is the differentiation of human activities from background 'natural' fires caused by lightning strikes, rock falls and volcanic eruptions (Haberle 1994, pp. 190–91). Kershaw et al. (1997, p. 435) state:

> In assessing the human contribution to past biomass burning, the most reliable estimates are probably derived from complex rainforest existing under high, seasonally evenly distributed, rainfall where natural fires are unlikely to occur, and on small oceanic islands where natural ignition sources are limited.

For moist, lowland and montane forests in New Guinea, carbonised particle frequencies are largely assumed to be the product of human agency (Corlett, 1984, pp. 852–53). Haberle et al. (1991, p. 31) stated: "that fire is not recorded from sites in the cool wet montane forests prior to the appearance of human activity". However, carbonised particles in sediments dating to c. 60,000 BP at Lake Haeapugua (Haberle, 1993) and c. 50,000 BP at Kosipe Swamp (Kershaw et al. 1997, p. 429) have been discounted as probably natural, even though the antiquity of these events is within the plausible age of human colonisation for New Guinea.

Late Pleistocene/Early Holocene Disturbance across New Guinea

Early anthropogenic disturbances of Highland vegetation date to c. 41,000–38,000 cal BP at Kosipe Swamp (Hope, 2009), 30,000–25,000 BP at Supulah Quarry (Haberle et al., 1991, pp. 30–31) and 31,500–33,500 BP at Supulah North Pond (Hope, 1998) in the Baliem Valley. These burning events are interpreted to potentially represent crop-procurement practices intended to enhance the productivity of favoured plants, such as *Pandanus* spp. at Kosipe Swamp (Hope and Golson, 1985, pp. 822–3; see White et al., 1970). Golson has suggested that human use of the Highlands as a whole during the Pleistocene focused on *Pandanus* spp. (Golson, 1991), although this is problematic (Denham, 2007).

Estimates of tree-line altitude suggest climates in the Highlands stabilised by around 9000 BP (Hope and Peterson 1975, p. 158) following glacial retreat commencing at 15,000–14,000 BP (Bowler et al., 1976, p. 362). From the LGM to around 11,000

Site	Altitude (mAMSL)	Commencement (cal BP)	Reference
Mid-altitude, Inter-Montane Sites			
Lake Haeapugua, Tari Basin	1650	14,5-12,000	Haberle 1998
Kuk Swamp, Wahgi Valley	1560	pre-9000	Haberle et al. 2012
Telefomin, Ifitaman Valley	1500	18-15,500 11,5-8,200	Hope 1983
Kelela Swamp, Baliem Valley	1420	pre-7,000	Haberle et al. 1991
Higher and lower altitudes			
Laravita Tarn, Mount Albert Edward	3780	12,000	Hope 1980
Ijomba Mire, Discovery Valley	3720	c.11,000	Hope 1996
Lake Hordorli, Cyclops Mountains	780[1]	11,000	Hope and Tulip 1994
Lake Wanum, Markham Valley	35	8,500	Garrett-Jones 1979

Table 1. Selected palaeoecological evidence of Late Pleistocene to Early Holocene anthropogenic disturbance in New Guinea.

BP, the mid-altitude valley floors were blanketed with *Nothofagus*-dominated forests, after which date sites between 1200-1960 m "were invaded by lower altitude taxa, leading to a complex mixed forest" (Hope, 1996, p. 178). Given the large contribution to the pollen rain at high altitudes, these beech forests were possibly monostands, with few other species represented, as described for contemporary high altitude areas of Papua New Guinea (Read et al., 1990) and West Papua (Hope, 1976, pp. 124-5). Pollen diagrams document an increased presence of *Castanopsis*, *Lithocarpus*, *Podocarpus* and other mixed forest species at the beginning of the Holocene. The demise of beech stands in the mid-altitudes was due to "a release of many of the mid-montane valleys from cloudy and misty conditions and possible periodic severe frosts" (Hope in Hope et al., 1983, p. 40) and was accompanied by an increased "floristic and structural complexity" (Hope et al. 1988, p. 603).

In the late Pleistocene/early Holocene, a number of clearances occurred in large inter-montane valleys at 1400-1650 m, although the character of these clearances varied and they were not unidirectional (Table 1). For instance, the elevated charcoal and disturbance taxa frequencies for Lake Haeapugua from 22,000-10,000 BP were followed by invasion of the site by swamp forest (Haberle, 1993, pp. 214-5, 1998, p. 11). Two early episodes of prolonged clearance followed by

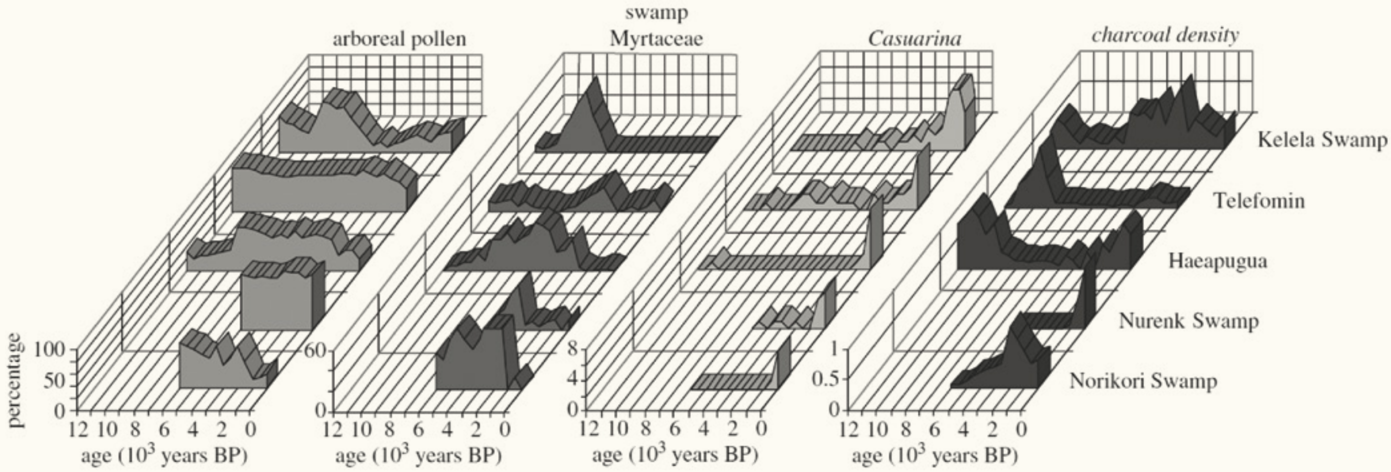

Figure 3. Selective pollen diagram showing the variable nature and timing of disturbance, degradation and destruction of tropical rainforests for five highland valleys during the Holocene (Haberle 2007: Fig. 2). Note the percentages of arboreal and swamp (Myrtaceae) forest taxa, the anthropic planting of Casuarina as a tree-fallowing practice, and charcoal frequencies indicative of burning. Nurenk exhibits anthropic disturbance within the last few hundred years, whereas Telefomin, Haeapugua and, to a lesser extent, Kelela Swamp (western New Guinea) indicate major burning at the beginning of the Holocene.

forest recovery were documented for Telefomin (Hope 1983). In contrast, the record for Kelela Swamp in the Baliem Valley records change from the beginning of the diagram before c. 7800 cal BP, with an increasingly disturbed environment to the present (Haberle et al. 1991). Additionally, Laravita Tarn on Mount Albert-Edward displayed a continual fire record from 12,000 BP (Hope, 1980, p. 244). Similarly, early Holocene warming and increased precipitation did not lead to forest encroachment and the replacement of grasslands in the Upper Wahgi Valley. Rather forest advance was 'muted' and a mosaic of grassland and forest subject to episodic burning persisted (Haberle et al., 2012; also see Denham et al., 2003, 2004). Haberle et al. (2012, p. 136) ask a rhetorical question: "What were people doing at Kuk Swamp to restrict the advance of forest due to rapid and significant climate change during the Terminal Pleistocene [and early Holocene]?"

The palaeoecological data indicates that as climates ameliorated after the LGM people occupied the large inter-montane valleys with greater magnitude and frequency, for longer periods and used the expanding resource base more intensively (Golson, 1991). These clearances were not ubiquitous, and some sites show no sign of human impact until the mid Holocene or much later (Figure 3). For example, Nurenk Swamp at 1950 m shows no signal until 300 BP (Hope et al., 1988, p. 614).

Mid Holocene Disturbance in the Wahgi Valley

From her work at several sites in the Wahgi Valley, Powell documented disturbance to the primary forest that pre-dated 5300-5000 BP (Powell, 1970). Powell interpreted the evidence to represent anthropogenic disturbance, whereas Walker

(1970, p. 220), in reviewing Powell's work, did not ascribe a definite cause. At Draepi-Minjigina (Powell, 1970) and Lake Ambra (Powell, 1981) in the Upper Wahgi Valley, there were gaps in the record between the late Pleistocene and mid Holocene levels. These two sites signalled a change from undisturbed primary forest in the late Pleistocene to a disturbed environment with higher percentages of woody non-forest species by the mid Holocene. Similarly, the M1 core from Warrawau depicted the establishment of secondary forest from the beginning of the pollen diagram at c. 5000 BP (Powell, 1970; Powell et al., 1975, pp. 43–4, 46–8). Secondary forest was represented by light demanding species including *Trema* sp., *Acalypha* sp., *Macaranga* sp. and *Dodonaea* sp. These Wahgi Valley sites record a further decline in forest cover up to 4000 BP with concomitant rises in grass frequencies.

In contrast, the record from Kuk Swamp shows disturbance to the montane forests from the Terminal Pleistocene to early Holocene, with more persistent and cumulative change during the early Holocene. A dramatic change in palaeoecology of the Kuk catchment occurs around 7000 years ago. The rainforest and swamp forest signals drop precipitously with a corresponding increase in herbaceous taxa, primarily grasses and sedges (Denham et al., 2004; Denham and Haberle, 2008; Haberle et al., 2012). Effectively, the valley floor within the Kuk catchment was degraded to grassland and other disturbed vegetation communities at this time. Although no other palaeoecological records in the Upper Wahgi Valley extend as far back in time, several records show the existence of grasslands and heavily disturbed environments, albeit with localised periods of forest recovery, from around 5000 years ago (Powell, 1970; Denham et al., 2004; Sniderman et al., 2009).

An anthropic landscape dominated by grasslands persisted on the floor of the Upper Wahgi Valley until the arrival of Australian-based gold prospectors and a government officer in 1933 (Leahy, 1936). These grasslands were maintained by periodic burning and, presumably, cultivation. Such degraded environmental conditions are characteristic of previously cultivated areas across the Highlands today (Gillison 1982).

Differentiating the human signal

The differentiation of climatic, anthropogenic and other influences on pollen diagrams from New Guinea is problematic (Walker and Hope, 1982; Swadling and Hope, 1992, p. 26; Haberle, 1994). However, anthropogenic signatures have been identified that enable the human impact on the landscape to be gauged and differentiated from climatic influences (Haberle, 2007; Haberle et al., 2012). The clearest of these are increased charcoal particle frequencies associated with a long-term decline in primary forest values and a concomitant rise in disturbance taxa including secondary forest, non-forest and grassland species (after Haberle, 1994).

It does seem probable that people were engaging in more intensive and extensive subsistence practices at the end of the Pleistocene and beginning of the Holocene. The indicators of anthropogenic clearance are present for a number of large inter-montane valleys at this time. The signals, however, are not all strong, permanent or unidirectional. Although there is some variability in the Upper Wahgi Valley pollen diagrams for the pre-5000 BP to 4000 BP period, they all register a degradation of the flora probably due to human practices in the respective catchments. The intensity and/or scale of human clearance may have increased during this time, with evidence of contemporary clearances elsewhere in the Highlands.

Most importantly to understanding long-term human adaptation to rainforests on New Guinea is the problem of interpreting, or reading, these long-term palaeoecological records in terms of archaeologically meaningful periods and practices. Is there a simple correspondence between level of forest disturbance and intensity of subsistence practice that can be read from the palynological records? Do the late Pleistocene/early Holocene disturbances of the rainforest represent a more intensive subsistence strategy to the preceding procurement, especially of *Pandanus* spp.? Can the mid Holocene clearances in the Wahgi Valley, which are associated with agriculture, be used as an analogue elsewhere of more intensive subsistence practices? These questions are only partially resolvable given the limited archaeological evidence for the highlands.

Lines of Evidence 2: Archaeology

Archaeology provides direct evidence of human practices in the past. Here the focus is upon human adaptation to the rainforests of New Guinea, with an emphasis on the highlands. There are five major lines of evidence that are relevant: wetland archaeology provides evidence of former plant exploitation practices and cultivation; occupation sites indicate where and how people were living in the landscape; artefacts indicate the technology available to people to interact with their environment; archaeobotany yields macroscopic (nuts, seeds and wood) and microscopic

Site Name	Altitude (m)	Location	Main Field Seasons	Earliest Evidence (cal BP)	Key Publications
Tambul	2170	U. Kaugel Valley	1976	4600-4100	Golson 1997
Mogoropugua	1890	Tari Basin	1980	700-300	Ballard 1996
Minjigina	1890	U. Wahgi Valley	1967	c. 2000-1000	Powell 1970; Golson 1982
Ambra Crater	1760	U. Wahgi Valley	1999	560-500	Sniderman et al. 2009
Haeapugua	1650	Tari Basin	1991-1992	3000-2000	Ballard 1996
Kindeng	1600	U. Wahgi Valley	1968	n/a	Unpublished
Warrawau (Manton's)	1590	U. Wahgi Valley	1966, 1977	c. 6000-5000	Golson *et al* 1967; Lampert 1967; Powell 1970
Kuk	1560	U. Wahgi Valley	1972-1977, 1998-1999	10,000 7000-6400	Golson 1977; Denham et al. 2003; Golson et al. in press
Mugumamp	1560	U. Wahgi Valley	1977	c. 4000	Harris and Hughes 1978
Kana	1480	M. Wahgi Valley	1993-1994	3000-2000	Muke and Mandui 2003

Table 2. The earliest evidence for prehistoric cultivation at wetland archaeological sites in the highlands.

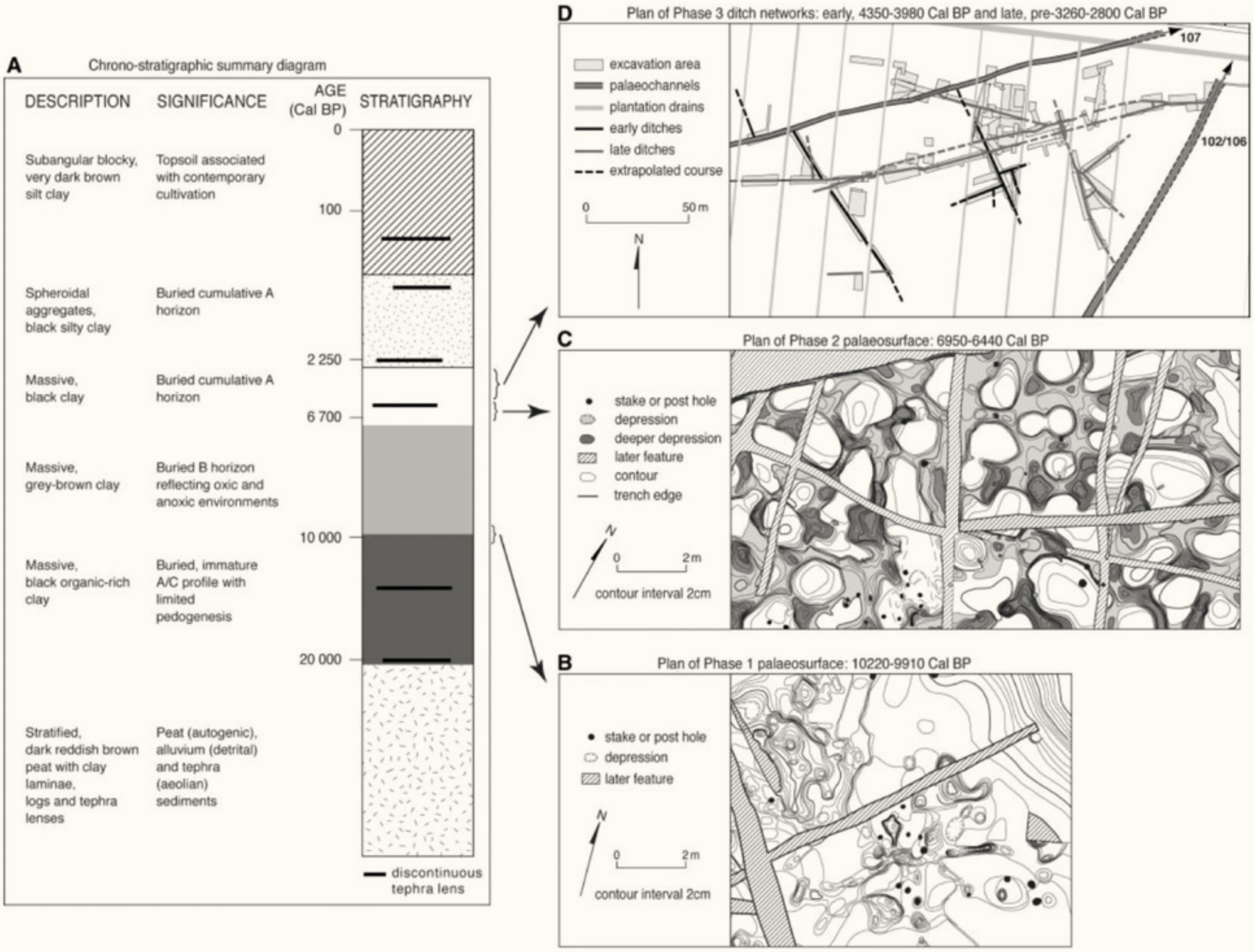

Figure 4. Archaeological and stratigraphic summary of the early evidence for plant exploitation and cultivation at Kuk Swamp (Denham et al. 2003: Fig. 2): Phase 1 represents plant exploitation on the wetland margin Phase 2 represents mound cultivation, and Phase 3 represents drainage of the wetland using ditches.

(phytoliths, starch grains and parenchyma) evidence of former plant use; and, zooarchaeology provides evidence of past faunal exploitation, with an emphasis on hunting, gathering and processing of vertebrates.

Wetland archaeology

Wetland archaeology sites in the highlands of Papua New Guinea have provided some of the earliest evidence for plant cultivation in the world (Table 2; Figure 4; Golson, 1977; Golson and Hughes, 1980; Denham et al., 2003; Golson et al., in press). The type site at Kuk Swamp not only provides palaeoecological records of forest disturbance during the Pleistocene and early Holocene, with dramatic clearance in the mid Holocene, but has also yielded the most robust chronology for the emergence of agriculture on the island.

At 10,000 cal BP, the wetland margin at Kuk provides evidence of localised forest clearance, microtopographical manipulation, and plant exploitation of an aroid (cf. *Colocasia esculenta*) and a yam (*Dioscorea* sp.) (Denham et al., 2003; Denham, 2004; Fullagar et al., 2006). Subsequently, there is evidence for mound cultivation, including of bananas (*Musa* spp.), at 7000–6400 cal BP, with comparable yet later evidence documented at two other wetlands in the Upper Wahgi Valley – Warrawau and Mugumamp (reviewed in Denham, 2003). The earliest ditched drainage of wetlands in the highlands dates to approximately 4400–4000 cal BP based on rectilinear drainage networks at Kuk and a wooden digging implement collected from a ditch at Tambul (Golson, 1997; Denham, 2005a). The agricultural chronology at Kuk has established New Guinea as a centre of early agriculture and plant domestication, including of bananas (*Musa* cvs.), sugarcane (*Saccharum officinarum*), sago (*Metroxylon sagu*), root crops (including *Dioscorea* sp.) and several locally important pandans (*Pandanus* spp.), cane grasses (e.g., *Setaria palmifolia*) and tree crops (including *Terminalia* and *Canarium* species) (Yen, 1973, 1990, 1995; Denham 2011). The global significance of Kuk is recognised through its inscription on the World Heritage List (Muke et al., 2007).

Occupation sites

Although New Guinea is the second largest island in the world, relatively few occupation sites have been investigated in detail. In the highlands of Papua New Guinea, occupation occurred in caves, rock shelters and open sites from soon after first colonisation, with clear evidence of house structures only dating to the last 4500–4000 cal BP or so. There are clear preservation biases: chronologically, older sites are harder to identify and find; while geographically, open sites are more

Site Name	Altitude (m AMSL)	Earliest Occupation (cal BP)	Primary References
Mapala	3996	6500-5900	Hope and Hope 1976
Kamapuk	2050	5300-4800	Aplin 1981
Ivane Valley/ Kosipe	2000	49,000-43,000	White *et al.* 1970; Summerhayes et al. 2010
Manim 2	1770	10,800-10,200	Christensen 1975
Wañelek	1710	19,400-17,300? 4100-2800	Bulmer 1977, 1991
NGH	1700	4400-3800	Watson and Cole 1977
NGG	1680	3800-3300	Watson and Cole 1977
Nombe	1660	25,500-19,600	Mountain 1991; Denham and Mountain 2016
NFB	1650	4800-4000	Watson and Cole 1977
Aibura	1640	4500-3900	White 1972
NFX	1550	23,600-20,000?	Watson and Cole 1977
Kiowa	1530	12,600-11,600	Bulmer 1966
Kafiavana	1350	13,300-11,600	White 1972
Batari	1300	9500-8700	White 1972
Yuku	1280	15,300-13,300	Bulmer 1966

Table 3. Earliest occupation of pre-2000 cal BP cave, rock shelters and open sites in the highlands of New Guinea (excluding wetlands)

likely to have been weathered, eroded, reworked by cultivation and thereby destroyed than caves and rockshelters. Consequently, the use of summed site numbers, artefact frequencies or radiocarbon dates to imply occupation intensity is methodologically unsound.

Sites pre-dating the Last Glacial Maximum are relatively sparse in the highlands (Table 3; Figure 1): several open sites in the Ivane Valley landscape date to the period of early colonisation, potentially pre-40,000 cal BP (Summerhayes et al., 2010); and, the rockshelter of Nombe was occupied periodically from 25,500-19,600 cal BP (Denham and Mountain, 2016). Comparably early sites have also been documented in the lowlands, most significantly the open site of Bobongara on the Huon Peninsula (Groube et al., 1986).

A greater number of caves and rockshelters were first occupied during the Terminal Pleistocene and early Holocene. Several provide well-dated and robust chronologies for much of the Holocene, principally Kiowa (Bulmer, 1966; Gaffney et al., 2015a), Manim (Christensen, 1975) and Nombe (Mountain, 1991; Denham and Mountain, 2016). As yet, modern technologies of archaeological science have not been applied to the assemblages from these sites to any degree, especially in regard to obtaining comparable archaeological evidence of animal and plant processing and consumption practices to complement the agricultural chronology from Kuk and other wetlands.

The oldest reliably dated house sites derive from c. 4500 years ago at multiple sites in the highlands. Although potentially earlier house sites have been reported from Wañelek (Bulmer, 1977, 1991) and NFX (Watson and Cole, 1977), these are fraught with uncertainty (Denham and Ballard, 2003; Denham, 2016b). It may be coincidental that the earliest sedentary structures broadly correspond with the earliest drainage networks. Although there is no correlative link, both sedentism and drainage networks suggest greater territoriality among groups, which can also be implied by the more widespread, dramatic and persistent forest clearances across several major highland valleys. The emergence of greater territoriality at this time and could potentially be reflected in rock art traditions and have fostered a greater sense of community identity (although there is no robust data on these).

Artefact trends

Associated with trends in occupation, there are trends in material culture, especially types of stone artefact in the highlands. Although the early tool kit of highlanders largely comprised relatively coarse pebble tools and primarily unifacial implements, it also included waisted blades (Summerhayes et al., 2010; also see Groube et al., 1986). As discussed above, these tools were multi-functional and assisted people to live in rainforests. A major technological innovation occurred during the Pleistocene – edge grinding (White, 1972;

also see Hiscock et al., 2016), although the ubiquity of the technology increased dramatically during the mid-Holocene (Christensen, 1975). The prevalence of ground axe-adzes in highland environments, especially the Upper Wahgi Valley, is coincident with dramatic forest degradation at Kuk around 7000 years ago. Certainly, the presence of ground axe-adzes would have facilitated forest clearance in comparison to previously edge ground or unground implements (Bulmer, 1966; Christensen, 1975). Regional refinements in stone tool production occurred in the highlands with the advent of planilateral quadrangular axe-adze production at quarries (Burton, 1984) and variable hafting styles (Crosby, 1973), while other groups persisted in the adventitious use of river cobbles and pebbles for lithic manufacture (Swadling, 1983).

Although many of these stone tool traditions may represent technological innovations within the interior of New Guinea, the highlands were not cut off from broader regional cultures and technologies during the Holocene. A mosaic of local exchange networks, as well as occasional long-distance trade along waterways and over mountain ranges, resulted in the net movement of items and ideas between the coast and the highlands interior (following Hughes, 1977). Items trade into the interior included stone mortars, pestles and figurines (Torrence and Swadling 2008); obsidian (White, 1972); multiple species of seashell that were used as valuables and for ornamentation; as well as pottery and the technology involved in its manufacture (Gaffney et al., 2015b; Huff, 2016).

Archaeobotany

Archaeobotanical records of plant use, processing and consumption in the highlands, like for the island as a whole, are limited. The majority of records document the use of *Pandanus* spp. in the highlands (Pleistocene and Holocene; Donoghue, 1989; Summerhayes et al., 2010), whereas those from the lowlands record the exploitation of a range of tree crop species (primarily Terminal Pleistocene and Holocene; Swadling et al., 1989; Fairbairn, 2005). In addition, residue analysis has identified the exploitation of root crops: a yam (*Dioscorea* sp.) during the Pleistocene at Ivane Valley (Summerhayes et al., 2010); and, aroid and yam during the early and mid-Holocene at Kuk Swamp (Fullagar et al., 2006). Additionally, potential bottle gourd (*Lagenaria siceraria*; Powell, 1970) and wax gourd (*Benincasa hispida*; Matthews, 2003) have been documented from mid-Holocene context at Warrawau and from 3000–2000 cal BP context at Kana, respectively. Both gourds are introductions to the island and yet both have been cultivated in the highlands for millennia. More recent finds, dating to the last few hundred years, have identified sweet potato (*Ipomoea batatas*) and sugarcane (*Saccharum officinarum*) from ditches and domestic contexts at Kuk Swamp (Lewis et al., 2016).

Overall, the application of modern archaeobotanical techniques on mainland New Guinea has been limited and available data is of limited use for understanding past land uses, including the emergence of agriculture. Consequently, interpretations of

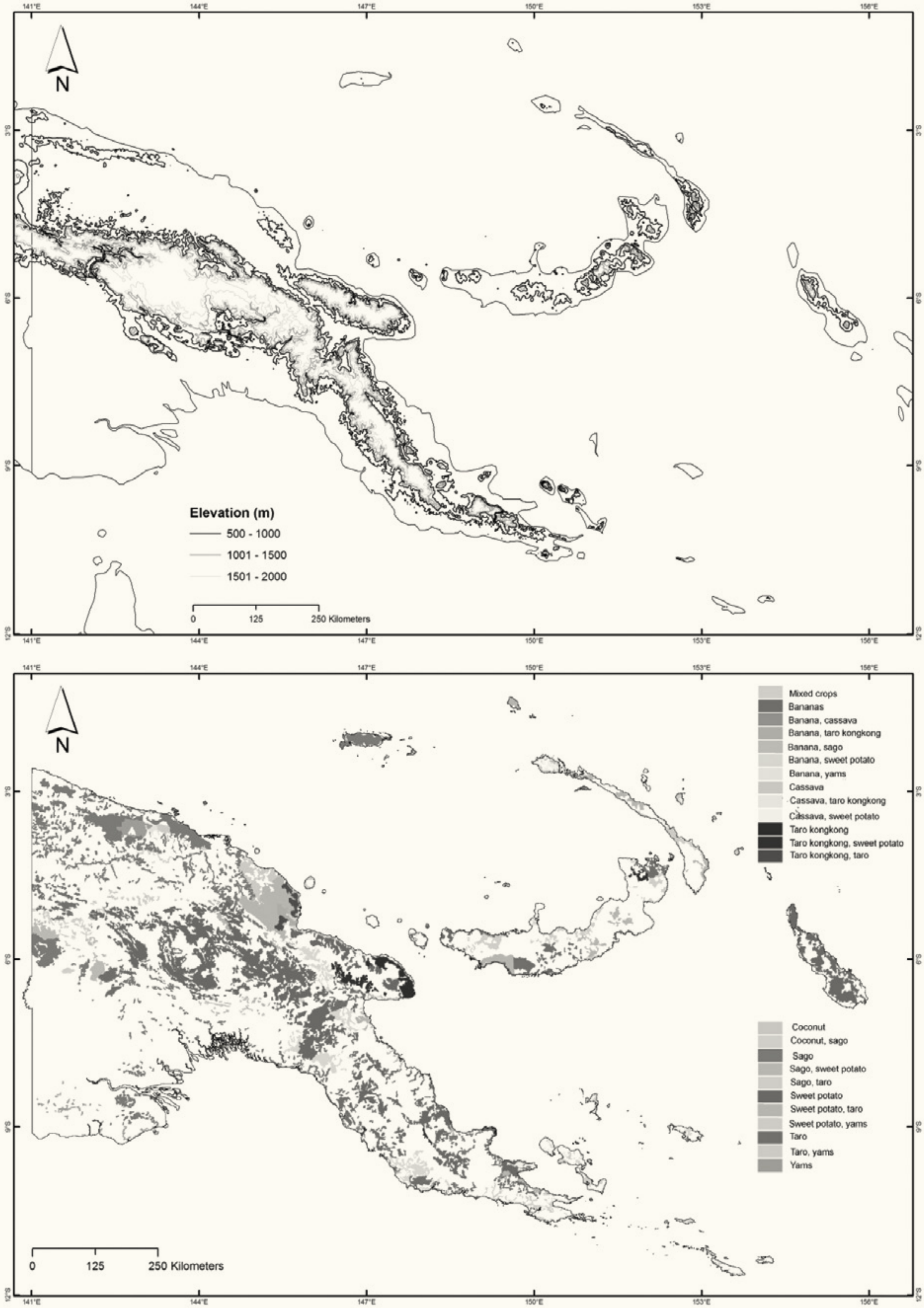

Figure 5. Topographic map of Papua New Guinea (upper) and map of geographical variation in primary cultivars across New Guinea today (lower) (Denham 2011: Fig. 3; derived from Bourke and Allen 2009).

plant exploitation are heavily on ethnography and agronomy, which have mapped in detail variations in crop plants and agricultural practices across Papua New Guinea (Figure 5; Bourke and Harwood, 2009). It can be inferred that similar variability occurred in the past – in terms of primary crop plants – as a result of environmental tolerances and cultural preferences (Denham, 2005b, 2011).

Just as the palaeoecological record indicates considerable variation in the records of forest disturbance, degradation and destruction from valley-to-valley, as well as from region-to-region, there was considerable variability in the nature of plant exploitation practices across the island. These practices included intensive, semi-permanent agriculture; swidden cultivation; arboriculture (including managed stands of sago); and hunting-gathering. These variations not only represent different types of subsistence practised by different groups, some groups engaged in multiple different practices in different parts of their territory. For example, groups may maintain intensive, semi-permanent plots on a wetland margin, swidden plots on the forest margin, stands of *Pandanus* within the remote forest, and gather plant resources throughout the landscape (e.g., Bowers, 1968). As such, each type of practice is not a mutually exclusive strategy, rather it forms

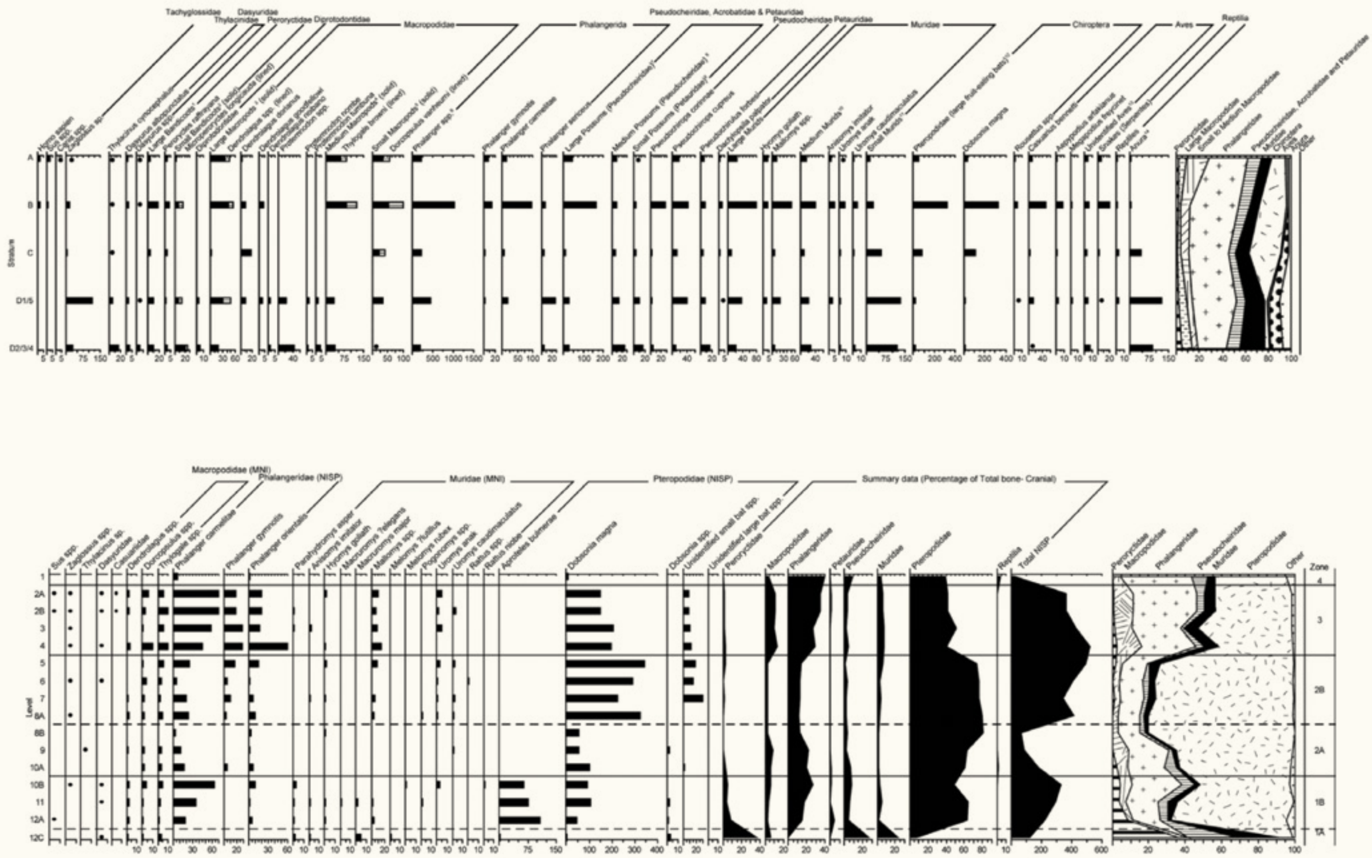

Figure 6. Archaeozoological summaries for Nombe rockshelter (upper) and Kamapuk rockshelter (lower) (Sutton et al. 2009: Figs. 7 and 8; derived from data in Mountain 1991 and Aplin 1981, respectively).

part of the repertoire that people are able to draw on within the landscape (Denham and Haberle, 2008).

Archaeozoology

Following initial arrival and exploration of the interior, it can be surmised that people would have hunted, as their ancestors had done on Sunda. The earliest record of hunting on New Guinea comes from Nombe, where the lowest layers preserve stone tools and megafaunal remains extending back to 25,500–19,600 cal BP (Figure 6; Denham and Mountain, 2016). If the Nombe evidence is taken at face value, there is a megafauna-human occupation overlap of at least 20,000 years in the highlands of New Guinea. This would contrast with records elsewhere in Australia and the world that generally suggest relatively rapid extinctions following human colonisation (e.g., Roberts et al., 2001). Certainly, thylacines (*Thylacinus cynocephalus*) went extinct on New Guinea, like mainland Australia, during the mid-to-late Holocene (Mountain, 1991) and most likely due to the introduction of the domestic dog (*Canis familiaris*). In sum, multiple species of megafauna went extinct on New Guinea following human colonisation, although the palaeontological record is limited and the extent to which different species survived is not known (Flannery et al., 1983; Flannery, 1995; Sutton et al., 2009).

Other species have undergone local extirpations or have had their range severely curtailed as a result of human activity. For example, the giant Bulmer's fruit bat (*Aproteles bulmerae*) was thought to have gone extinct in the pre-modern era, but a colony has subsequently been found in a remote region of the island (Flannery, 1995). Bats are particularly susceptible to population collapse given that hunting techniques can lead to the destruction of entire colonies (Mary-Jane Mountain, pers. comm.). Other species, such as long-beaked echidnas (*Zaglossus* spp.) are susceptible to disturbance by people and will avoid densely inhabited regions. Consequently, their absence from a zooarchaeological record need not indicate extirpation as a result of predation, but may reflect anthropogenic disturbance and habitat destruction.

Instead of solely representing the species' composition of the local environment, archaeozoological records reflect the preferences of the people who used or lived in a cave or rockshelter (Bulmer, 1976). The zooarchaeological signatures of a male hunting party and a camp used by women and children would likely be very different. Due to issues of preservation, the archaeozoological record is highly skewed to large and medium vertebrates, with small vertebrate remains less likely to preserve or be collected during excavation (Sutton et al., 2009). Further, few invertebrates remains are likely to preserve, even though they may have been regular contributors to diet in the past.

Due to the above considerations, the translation of zooarchaeological records into land use practices can be problematic. However, a general reduction in the deposition of faunal and artefactual material does occur in caves and rockshelters across the highlands during the mid-Holocene. This trend is likely associated with multi-disciplinary evidence for increased forest clearance, an increased reliance on cultivation and increased sedentism, especially from c. 4500–4000 years ago. With the establishment of house structures within open settlements and agronomic landscapes, people likely used caves and rockshelters less as places of habitation – whether permanent, semi-permanent or seasonal – and more for male rituals, hunting parties and temporary shelters when gathering or cultivating.

Furthermore, the character of hunting likely changed following the introduction of the domestic dog, pig (*Sus scrofa*) and chicken (*Gallus gallus*) to the island within the last 3000 years. Although dogs would have greatly enhanced hunting (Dwyer and Minnegal, 1991), pig husbandry and associated feral pigs would have provided alternative sources of protein to game within the last 1200 years or so (Sutton et al., 2009). Furthermore, as pig husbandry intensified in the last few hundred years in some highland valleys – and especially following the widespread adoption of the sweet potato (*Ipomoea batatas*), hunting of wild species probably became less significant for subsistence. In many regions, hunting has become more closely associated with male prowess, status and seclusion during initiation, as well as important for the capture of live game (i.e., cassowary, *Casuarius* spp.) for exchange, bird-of paradise feathers and marsupial fur for exchange and ornamentation, and game meat for traditional ceremonies and rituals.

Ranges of Variability

The multiple lines of palaeoecology and archaeology enable general trends in the long-term history of human occupation of New Guinea to be identified, especially the highlands of Papua New Guinea. However, how are these long-term trends to be conceptualised and made useful for management of tropical rainforest environments in Papua New Guinea today?

Foremost, these records indicate that the rainforests of New Guinea, like those elsewhere in the world, have been cultural landscapes modified by people since the arrival of *Homo sapiens*. The character of the impacts of people on tropical rainforests are multifarious, but can be characterised in terms of threefold division.

- Disturbance – in the form of localised clearance and maintenance of patches within the forest using waisted blades and fire, as well as preferential hunting of species, since initial colonisation of the island over 40,000 years ago. Although individually minor, these disturbances did lead to long-term changes in rainforest ecology – primarily through the extinction and extirpation of faunal species, as well as through accelerating gap and edge dynamics. However, the impacts of these disturbances were sufficiently low to enable ecosystem regeneration and the maintenance of ecosystem function.

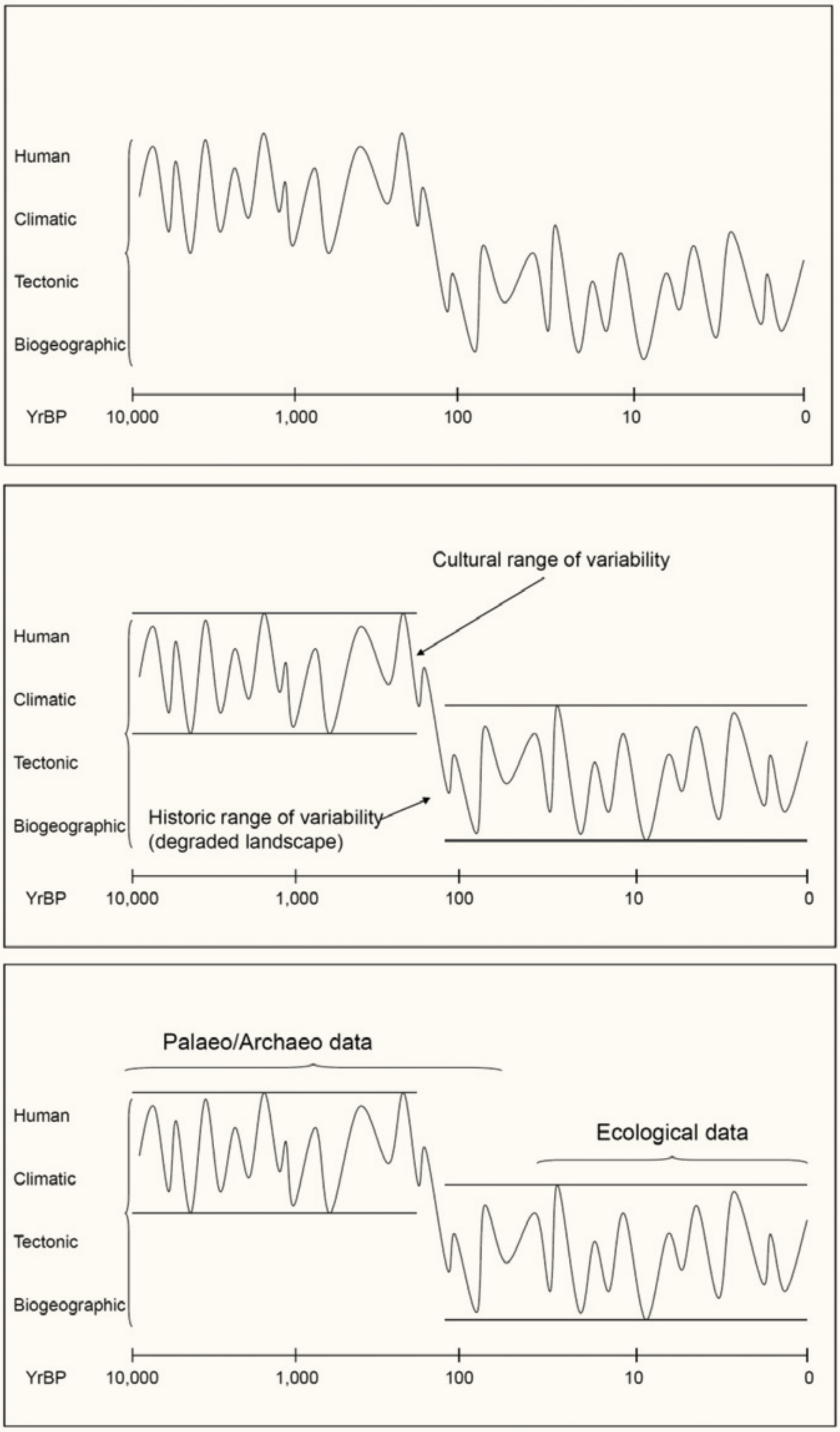

Figure 7. Schematic representations of: (upper) ecosystem variability in response to a number of anthropic and natural variables during the Holocene; (middle) with superimposition of cultural and historic (post-European) ranges of variability showing stepped change in ecosystem dynamics; and, (lower) associated lines of evidence useful for inferring ranges of variability in the past, namely, palaeoecological and archaeological data for millennial to centennial timescales and ecological data for decadal and annual timescales.

- Degradation – represents the reduction in ecosystem biodiversity and resilience due to the cumulative removal of faunal and floral species. Although canopy species may persist, the dynamics of the rainforest ecosystem are fundamentally altered through over-hunting and over-exploitation of favoured plant species, as well as increased frequencies of disturbance. In sum, impacts result in a stepped-change in ecosystem function, even though major elements of the rainforest canopy and subcanopy can be retained.

- Destruction – through persistent clearance of the rainforest, especially with reduced fallow periods following clearance for cultivation and repeated burning, can eventually prevent regeneration of rainforest and the establishment of subclimax vegetation communities, such as grasslands and secondary forest. Effectively continued human intervention results in the replacement of the tropical rainforest environment with another ecosystem.

These degrees of impact are relatively arbitrary and overlapping; namely, they are heuristic and not mutually exclusive. Yet there are clear shifts, or thresholds, between them in terms of the degree of impact upon tropical rainforests. Although chronologically these levels of transformation can be mapped successively across the New Guinea highlands, they also occur differentially across landscapes today.

Through time, human practices have resulted in stepped changes to the tropical rainforests on New Guinea. Each stepped change marks a threshold between different ranges of variability characterising tropical rainforest ecosystems in time (Figure 7; following Landres et al., 1999; Keane et al., 2009). These ranges of variability effectively constitute baselines against which change and conservation targets can be measured.

Pre-human rainforests can be characterised as reflecting a range of processes of varying magnitude and frequency. The effects of short-term changes, such as earthquakes and volcanic eruptions, are superimposed on long-term changes, such as glacial cyclicity. Together they constitute a natural range of variability for tropical rainforests, rather than equilibrium. Given that the natural range of variability for different ecosystems on New Guinea occurred tens of millennia in the past, it is not a useful baseline for conservation; rather it provides a heuristic baseline for measuring changes resulting from different types of human activity.

Following human arrival on New Guinea, there were stepped changes in terms of ecosystem dynamics. Ecosystems have been subject to diverse cultural ranges of variability and stepped changes in functioning and biodiversity. These ranges of variability encapsulate differing degrees of disturbance, degradation and destruction in given geographical and temporal contexts.

For instance, tropical rainforests were disturbed following initial colonisation as a result of hunting, localised clearance and burning. However, these practices did not significantly degrade ecosystem functioning, although the effects of several large marsupial extinctions are not clear on New Guinea. Vast tracts of sparsely-populated lowland and some highland rainforests, especially those areas considered 'unpopulated', still only exhibit degrees of 'disturbance' today.

Continued human presence and management of the landscape, especially through resource intensification of favoured arboreal species (namely, creation of groves and stands of tree crop species such as *Pandanus* spp., *Metroxylon* sago, *Canarium* almond and *Terminalia* spp.) and more intensive hunting, have 'degraded' ecosystems. Degradation has not been uniform across the island, rather it is focussed in areas of denser settlement, whether by mobile or sedentary groups, and areas regularly visited by large groups on a seasonal or periodic basis for hunting, collecting and ritual.

The advent and spread of cultivation practices during the Holocene has increased the scale and character of transformation to rainforest environments; namely, it represents a stepped change in ecosystem dynamics and the creation of a new range of variability. Different types of agriculture are practiced across the island, from extensive arboriculture and shifting cultivation characteristic of the lowlands and highland fringes to intensive, semi-permanent cultivation on the floors of several highland valleys. Each type has its own range of impacts upon rainforests. Extensive practices of arboriculture and swidden cultivation can have high local impacts for a short duration; yet given that plot cultivation may only occur for 1-2 years before abandonment to fallow for over 15 years, the cumulative effects of these practices on ecosystems as a whole are limited – falling into the disturbance to degraded range. However, as fallow systems shorten and the frequency and density of shifting cultivation, as well as burning, increase, the impacts on the ecosystem as a whole become catastrophic: forests are destroyed and replaced by grassland and regrowth, or secondary vegetation communities. Throughout the Holocene, the intensity and extent of degradation and destruction to rainforests across New Guinea has greatly increased as a result of the adoption and spread of agriculture.

In recent decades, rates of rainforest degradation and destruction have accelerated further. In the highlands, the primary motors of change are expanding populations and the need for more land to grow subsistence and cash crops and for settlement. Not only do people want food, they also want to generate money in order to participate in the cash economy. In the lowlands, the primary motors of rainforest clearance are slightly different, most notably in terms of logging and oil palm plantations, as well as for subsistence and cash cropping.

These transformations of rainforest environments do not just occur through time, they also occur across space. Not only are there variations in terms of human impacts in different regions and valleys (Haberle, 2007), there are also differential impacts of communities within the same landscape (Bowers, 1968; Denham and Haberle, 2008). Often within an occupied territory there will

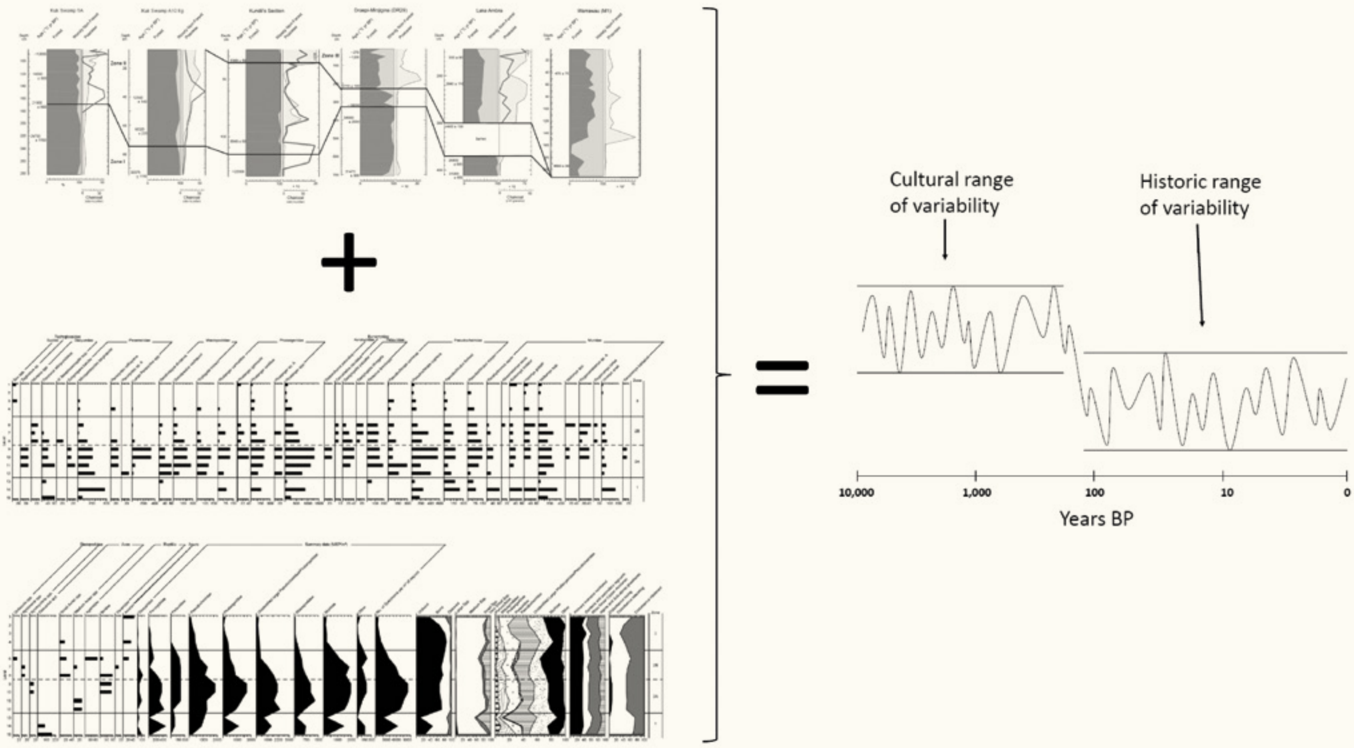

Figure 8. Schematic representation of how palaeoecological and archaeological data can be used to understand the cultural and historic ranges of variability for ecosystems in the highlands of Papua New Guinea.

be areas of cultivation and habitation, as well as more distant areas of resource exploitation and forest management, i.e., for hunting, gathering and arboriculture. Thus, the degrees of change to rainforest environments should not just be mapped chronologically, they also require a consideration of spatial variability from the deep past to the present.

Thinking of the Future

Since communities of early modern humans began to inhabit tropical rainforests, they have changed them. The tropical rainforests we see across the globe today are not 'natural environments', rather they represent the accumulation of millennia of human practices. These practices have different degrees of impact on forests, which can be exacerbated by climatic or environmental sensitising of forests to change; for instance, tropical rainforests are more susceptible to burning and clearance during droughts.

The tropical rainforest environments we value today are a cultural landscape. Any attempt to manage tropical rainforests needs to take into account how they were created (Figure 8), as well as the changing needs of the people who inhabit them today and their ways of life. Problems in tropical rainforest ecology and management have accelerated since these regions of the world have become enmeshed in the historical and modern world economy. Although people have cleared tropical rainforests for millennia, the character and scale of clearances has now changed. An understanding of traditional practices can thus only be a partial guide for the future.

Today, new or augmented pressures are leading to the rapid degradation and destruction of tropical rainforests across the globe. On New Guinea, these pressures include population growth, cash cropping and subsistence cultivation in the highlands, and these are greatly exacerbated by logging and oil palm plantations in the lowlands. Not only have populations grown, but also the ecological imprint of people has grown as they seek to participate in the modern economy of Papua New Guinea. They need to generate money for school fees, medicines, store bought goods, travel and so on. Arguably, though, the retention and maintenance of traditional lifeways can act as a buffer to more destructive practices, such as clear-fell logging and oil palm plantations. Indeed, some traditional practices may serve as a guide to developing conservation practices for the future.

As discussed, many communities across New Guinea undertook a range of practices across their territory. Some areas were used for habitation and gardening, with more remote plots, groves and hunting-gathering occurring across the broader landscape. In seeking to devise land management plans for the future, the traditional divisions of the territorial landscape will require revision to incorporate areas for selective logging and cash cropping, such as coffee and oil palm. Yet, in some ways, more intensive modern practices mirror traditional selective felling of trees (i.e., for canoes, haus tambaran and so on) and the establishment of extensive groves and stands of tree crops (i.e., *Pandanus* in the highlands and numerous species in the lowlands). Different areas within the landscape need to retain a sense of their differential use: some conserved and carefully managed for hunting and gathering, or set-aside as part of carbon credit schemes; while others undergo more wholesale modification. Such local-scale practices do not obviate the need for extensive tracts of land to be more intensively conserved as Conservation Areas, National Parks and World Heritage Areas. Local-scale, bottom-up conservation can complement more extensive, top-down conservation efforts.

There is no easy or ideal solution to the problem of human interactions with tropical rainforests in Papua New Guinea for the future. The country has development goals, populations are likely to continue to grow rapidly, and tropical rainforests will be negatively impacted. Conservation efforts need to be targeted on minimising the degrees of these impacts for as long as possible using a combination of top-down and bottom-up conservation efforts.

Acknowledgements

The section entitled 'Common Misconceptions' is extracted and amended from Denham 2016a. Many thanks to the organisers of the symposium Exploring Frameworks for Tropical Forest Conservation in Mexico City (24-26 January 2017) for inviting me to present and to contribute this article. Especial thanks to the National Commission for UNESCO in Mexico, Nuria Sanz, Dorian Rommens, Rachel Lewis and Robin Dennell.

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